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Combining in-trawl video with observer coverage improves understanding of protected and vulnerable species bycatch in trawl fisheries

Running head: *Video assessments of protected species bycatch*

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Abstract

Assessments of incidental wildlife mortality resulting from fishing rarely account for unobserved bycatch. We assessed protected and vulnerable wildlife species bycatch in an Australian trawl fishery by comparing in-trawl video footage with data collected by an on-board observer. Data were obtained from 44 commercial trawls with two different bycatch reduction devices (BRDs). Eighty-six individuals from six major taxa (dolphins, sharks, rays, sea snakes, turtles and sygnathids) were documented from video analysis, including the endangered scalloped hammerhead shark (*Sphyrna lewini*) and the critically endangered green sawfish (*Pristis zijsron*). Based on the 2008/09 fishing effort of 4,149 trawls and scaling from these results, we estimated the annual catch of protected and vulnerable species (±1 SE) at 8,109 ± 910 individuals. Only 34% of bycatch was expelled through the BRDs. Independent observer data for the 44 trawls showed that 77% of the landed bycatch from these taxa were dead when discarded. These results indicate that unaccounted bycatch in trawl fisheries can be substantial, and that current methods of recording bycatch on-board vessels are likely to underestimate total fishing mortality. We recommend gear modifications and their validation through dedicated observer coverage combined with in-trawl video camera deployments to improve current approaches to bycatch mitigation.

Key words: Incidental mortality, observer program, IUCN status, *Tursiops truncatus.*

Introduction

Despite continuous improvements in fishing technology, few fisheries are free of non-target, incidental catch, or bycatch (Kennelly 1995; Hall *et al.* 2000). Trawling is a particularly non-selective fishing method with high bycatch, and its effects on marine wildlife species that fulfil critical ecosystem functions or have high conservation value may be significant (Watling and Norse 1998; Roberts and Hawkins 1999). Many such species, including mammals, reptiles and elasmobranchs, have life history characteristics that limit their ability to recover from anthropogenic mortality, such as that resulting from interactions with fisheries (Reeves *et al.* 2003; Lewison *et al.* 2004). The evolution of the ecosystem approach to fisheries management and accreditation for sustainable fisheries by third parties, such as the Marine Stewardship Council, has placed increasing significance on understanding and mitigating the effects of fishing on non-target species (Cummins 2004; Hall and Mainprize 2004; Bellido *et al.* 2011).

The levels and effects of fishing-induced mortality on large marine wildlife vary between species and fisheries (Chopin and Arimoto 1995; Davis 2002), but estimating them quantitatively is challenging because of the logistical constraints of detecting unaccounted bycatch and verifying mortality (Broadhurst *et al.* 2006). However, even rare events can have significant effects on population viability (Lewison *et al.* 2009). Fishing-induced mortality through bycatch can result from a combination of sources, including: 1) the individuals interacting with the net that die and are not landed (unobserved bycatch (hereafter 'unaccounted bycatch') and unaccounted mortality); 2) those that remain in the net and are dead when landed on-board (observed bycatch and accounted mortality); and 3) individuals that are alive when landed on-board, but do not survive release (observed bycatch, but unaccounted mortality). Skippers and independent observers can report on the number of animals landed on-board the vessel, but are generally unable to quantify the post-release mortality of those animals that are released alive, or the number and fate of those animals that pass through the net during fishing, either through escape hatches or the mesh.

Although unaccounted bycatch has been identified as an important research focus (Alverson and Hughes 1996), it has received relatively little attention to date, either due to the inherent challenges in quantifying this type of bycatch and the difficulty of determining unobserved mortality, or because of assumptions that all discarded animals die (Chopin *et al.* 1996) and all escapees survive (Pascoe and Revill 2004). Furthermore, the fate of escaped or discarded bycatch is rarely considered in the manipulation, validation or improvement of fishing gear (Suuronen 2005; Broadhurst *et al.* 2006).

Australian marine mammals, sawfish, turtles, sea snakes, sygnathids (seahorses, pipefish and sea dragons) and some sharks and rays are listed as protected under the Environmental Protection and Biodiversity Conservation (EPBC) Act 1999. These taxa are incidentally caught in trawl fisheries around Australia (Stobutzki *et al.* 2001; Bache 2003; Brewer *et al.* 2006), including the Pilbara Fish Trawl Interim Managed Fishery (‘Pilbara Trawl Fishery’ [PTF] hereafter) of north-western Australia ((Stobutzki *et al.* 2001; Bache 2003; Stephenson and Chidlow 2003). The PTF operates in the waters of the North West Shelf, fishing an area of *ca.* 23,666 km^2 between depths of 50 and 100 m and targeting demersal teleosts, particularly snapper and emperor species (*Lutjanus* spp. and *Lethrinus* spp.) and Rankin cod (*Epinephelus multinotatus*) (Newman *et al.* 2011). Bycatch reduction devices (BRDs) were introduced to the PTF in 2006, primarily to mitigate against the bycatch of common bottlenose dolphins (*Tursiops truncatus*), as well as turtles, large sharks and rays (Stephenson *et al.* 2008). Bycatch research in the PTF has focussed on the incidental capture of dolphins and little is known of the catch rates of other listed species, such as sawfish, sharks, rays, sea snakes and sygnathids (Allen and Loneragan 2010; Jaiteh *et al.* 2013). Furthermore, the rates of expulsion of these taxa through specially designed escape hatches are poorly understood (but see Stephenson and Wells 2006; Stephenson *et al.* 2008).

Here, we describe the incidental catch of threatened, endangered and protected (hereafter 'TEP') species in the PTF by analysing underwater video footage recorded inside actively fishing trawl nets. These data were compared with those of the bycatch recorded on deck by an independent observer, in order to estimate total bycatch rates, including those normally unaccounted for by on-board only assessments. We distinguish between unaccounted bycatch, which can include both live and dead animals, and unaccounted mortality, which is difficult to ascertain even with detailed analysis of in-trawl video footage. This study therefore provides an estimate of unaccounted bycatch, but not of unaccounted mortality. We also provide a preliminary assessment of the performance of two different BRDs in reducing bycatch.

Materials and Methods

<u>Bycatch reduction devices and video footage</u>

Details of the dimensions of trawl nets, mesh sizes and BRDs are provided in Allen and Loneragan (2010) and Jaiteh et al. (2013). The BRDs used in the PTF in 2008/09 consisted of a metal exclusion grid and a bottom-opening escape hatch, which extended about 1 m from the grid towards the opening of the net and was covered by a loose skirt of netting (Fig. 1, Jaiteh *et al.* 2013). Two types of grids were trialled in BRDs during this study, both featuring vertical stainless steel bars with central sections of braided stainless wire. Grid 1 (Fig. 1a) was the older of the two grids and measured 2 m (height) x 1.2 m (width) (Stephenson *et al.* 2008). This meant that its diameter was larger than the 100-mesh diameter of the net, which caused it to lie at an angle of *ca.* 40°. It featured five vertical bars at 15.5 cm intervals and a horizontal crossbar mid-section. The newer model, hereafter Grid 2 (Fig. 1b), better fitted the diameter of the net; it also stood at a higher angle, had only four vertical bars, spaced 15 cm apart, and no horizontal crossbar.

The three vessels operating in the fishery in 2008 and 2009 completed a total of 4,149 trawls between September 2008 and October 2009, the timeframe for this study (S. Hood, MG Kailis Group, pers. comm.). Underwater video footage was recorded with high definition Sony video cameras (HDR-CX7) mounted inside trawl nets of one of the three vessels, from 44 trawls conducted during seven fishing trips and in all areas of the fishery (see also Jaiteh *et al.* 2013). The 44 sampled trawls represented *ca.* 1 % of the total fishing effort for that year. The spatial distribution of the trawls and the manner in which they were conducted were representative of normal operations across the fishery as a whole. Cameras were deployed inside the net, behind the BRD and facing upstream toward the opening of the net. The number, condition and fate of animals that entered the net, interacted with the BRDs and were recorded on video during the 44 trawls were compared with those that were landed on deck, recorded by the observer and subsequently discarded.

Data analysis

Video footage was analysed using the computer program EventMeasure (www.seagis.com.au). Continuous sampling (Altmann 1974) was used over the duration of each trawl to ensure that all interactions of the focal taxa with the BRDs were recorded. An interaction was defined as any form of contact between TEP taxa and the grid and/or escape hatch.

Efforts were made to determine the fate of all animals that interacted with the BRDs. However, this was often difficult, as it could not be confirmed whether motionless animals were simply motionless, in shock or dead, while others that left the net apparently alive may have died subsequently as a result of injury, stress or predation. To avoid false estimates of dead and live animals, all individuals that left the net through the escape hatch or meshing were defined as "expelled", while animals that remained inside the net until the end of the trawl were described as "retained" (*i.e.,* in the net, not by the fishers). Species were identified to the lowest taxonomic level possible and the behaviours displayed by individuals were recorded (Table 4).

All identified TEP species were pooled into six higher taxonomic groups: dolphins (Delphinidae), sharks (Selachimorpha), true rays (Batoidea), sea snakes (Hydrophiidae), turtles (Cheloniidae) and pipefish (Sygnathidae). The effectiveness of Grids 1 and 2 was assessed by comparing the proportion of individuals expelled from each grid with a chi-square test of independence. No turtles or pipefish were recorded interacting with Grid 1, so these two groups were excluded from the test.

We used simple random sampling without replacement from a finite population to calculate the total annual number of grid interactions of individuals within the above taxa and their standard errors from our video analyses (following Thompson 2002, p. 16). Data were combined from both grids, as we were interested in estimating the total number of interactions for all taxa for the fishery; the relative use of the grids during our study was representative of their use in the fishery as a whole. An unbiased estimate of T, the total number of annual grid interactions, was calculated using the formula:

$$\hat{\tau} = N\bar{y}$$

with the estimated standard error

$$\sqrt{\frac{N(N-n)s^2}{n}},$$

where N is the number of trawls (4,149), $\bar{y}$ the sample mean, n the sample size of analyzed trawls (44) and s the sample standard deviation. This estimation equation does not assume normality to calculate an unbiased total and its standard error. Total interactions were not estimated for individual groupings of taxa, or for the different BRDs, because of the limited numbers of trawls and relatively small number of interactions for individual taxonomic groupings.

Results

The total duration of the 44 trawls was 113 h and 23 min, with a mean trawl duration (± 1 SE) of 2 h 35 min ± 8 min (36% of trawls were within 3 SE of the mean). Eighty-six interactions with TEP species were recorded from video analyses of 42 trawls, while no such interactions occurred during two trawls. We identified 19 species from these 86 interactions, including six species of shark, nine species of ray, and one species each of dolphin, sea snake, turtle and pipefish (Table 1). The observer identified 18 species from the bycatch landed on deck, bringing the total number of identified species to 24 (Table

1). Eight of the species assessed for this study are listed on the IUCN List of Threatened Species as Vulnerable (three sharks and five rays, including *Manta* spp.), one as Endangered (the scalloped hammerhead shark *Sphyrna lewini*) and one as Critically Endangered (the green sawfish *Pristis zijsron*) (Table 1). Dolphins, turtles, pipefish, sea snakes and the green sawfish are protected under the EPBC Act (Table 1).

The total number of BRD interactions of the six studied taxa during the 4,149 trawls conducted in 2008/09 (mean trawl duration = 2 h 43 min), estimated from the video data from 44 trawls conducted in that year, was 8,109 (SE=910) individuals. Sharks and rays dominated the interactions, comprising 66% of the video-documented interactions and 92% of the observer-documented landings.

Overall, the BRDs reduced the landings of wildlife species by 34%; the remaining 66% of animals that interacted with the BRDs were retained in the net and landed on deck (Table 2). However, the two BRDs had differential rates of exclusion: a significantly higher proportion of all incidentally caught wildlife was expelled from nets with Grid 1 (16 individuals; 50% of bycatch interactions) than those with Grid 2 (13 animals; 24% of interactions) (χ^2_3 = 56.74, p <0.001, Table 2). This pattern was clearly evident for the sharks and rays, in which larger proportions of each were expelled from nets with Grid 1 (63% of sharks and 53% of rays) than those fitted with Grid 2 (39% and 17%, respectively, Table 2). A similar pattern was evident for sea snakes, with only three of 19 sea snakes escaping when caught in nets with Grid 2 (Table 2).

The three sea snakes that escaped did so by swimming upward after coming into contact with the grid and swimming through the mesh (Table 2). Video observations of dolphins, a turtle, sea snakes and some sharks identified frequent startle responses, whereby these taxa responded to physical contact with the exclusion grids by pushing upward against the upper surface of the net (Table 4). Two dolphins, one each in nets with Grid 1 and 2, respectively, exhibited this behaviour for several minutes before becoming motionless and falling through the bottom-opening escape hatch (Table 2). A dolphin that was entangled near the mouth of the net outside the field of view of the camera, and therefore not seen on video, was landed and recorded by the observer (Table 3).

The observer reported a total of 129 landed individuals from the six taxa for the 44 trawls (Table 3). Of these, 90 individuals (77%) were dead and 39 (23%) were alive when discarded (Table 3). The mortality rate recorded on-board by observers (77%), combined with the retention rate documented within the trawl net via video analysis (66%), equated to an observed total mortality rate of 51% for TEP species incidentally caught in the PTF. While video analysis allowed us to estimate the amount of unaccounted bycatch, it was not possible to determine the likely survival of these animals. Hence, a numerical estimate of unaccounted mortality and actual total mortality could not be calculated.

In addition to the number of retained TEP species documented from in-trawl video analysis, the on-board observer recorded animals that were not seen on video (Tables 2 and 3). The most notable discrepancy was in the higher numbers of small sharks and rays recorded by the observer than from the within-net videos from the same trawls (Tables 2 and 3). This discrepancy is explained by the fact that, depending on distance from the camera, water turbidity and the amount of fish and benthos in the net at any given time, some animals were less likely or impossible to detect on video. This included animals that were small in size, transparent in colour (*e.g.,* sygnathids), or that were caught in parts of the net outside of the camera's field of view. They did not interact with the BRD, but were, for example, enmeshed in the outer surface of the net, near the net opening, or at the codend while predating on catch from the outside of the net. Conversely, higher numbers of interactions with dolphins and sea snakes were recorded on video than were seen by the observer, since most escaped or were expelled from the net before winch-up.

Discussion

We provide an initial assessment of threatened, endangered and protected (TEP) species interactions with BRDs in trawl nets and an estimate of unaccounted, non-target bycatch using in-trawl video footage collected during commercial fishing operations. Our comparison of the interaction rates recorded on video and by an on-board observer demonstrates that the use of underwater video cameras mounted within trawl nets, in conjunction with an independent observer program, can improve the accuracy of bycatch assessments in trawl fisheries. While several studies have quantified unaccounted bycatch in trawl and other fisheries, the majority have focused on non-target fish and invertebrates, rather than TEP species. This study also represents one of only two assessments of bycatch composition and fate in the PTF in a decade of commercial fishing activity. The previous study, by Stephenson *et al.* (2008), was based on observer and skipper records of 1,384 trawls (1,156 with grids) and partial video recordings of 443 trawls. Despite sampling over thirty times the number of trawls, the number of individuals (144) recorded from within the same six taxa was only 1.6 times that recorded in our study. Furthermore, the number of species identified (six species within five broad taxa, including a combined grouping of sharks and rays) was much lower than that in our assessment (24 species within six broad taxa). Stephenson et al. (2008) only reported results for the video data for BRD interactions of dolphins (n=7, of which 4 were predicted dead at the time of expulsion) and turtles ('approximately 6'). Large sharks and rays were observed on video, but their numbers and fate were not reported (Stephenson *et al.* 2008). Our results suggest an estimated annual TEP species bycatch of 8,109 (SE=910) individuals in 2008/09. While based on a relatively small sample size, the number and diversity of interactions recorded in this study indicate that between 7,000 and 9,000 TEP individuals are subject to incidental capture in the PTF annually. These findings suggest that improved bycatch mitigation is needed in this fishery, and that in-trawl video monitoring of bycatch is a critical component for better estimating and monitoring bycatch in this and other trawl fisheries.

This study also provides information on the performance of two BRDs in expelling bycatch from trawl nets. The proportions of bycatch expelled from escape hatches differed between BRDs: those fitted with Grid 1 generally expelled bycatch more effectively than those with Grid 2. This may have resulted from a malfunction of Grid 1 due to its large size, which caused it to collapse to a low angle, thereby guiding animals down towards the bottom-opening escape hatch. This grid also had a horizontal crossbar, which prevented larger sharks and rays from becoming trapped between the vertical bars or swimming through to the codend, as observed more frequently in nets with Grid 2. Two of the three vessels that continue to fish the PTF use the newer Grid 2 design in their BRDs (J. Wakeford, M.G. Kailis Group, pers. comm.).

Overall, the BRDs reduced the landings of non-target species by 34%, with 66% of bycatch that interacted with the BRDs remaining in the net and being landed on deck. The numbers reported by skippers and independent observers therefore inevitably represent an under-estimate of TEP species bycatch. Observers alone cannot quantify actual total bycatch rates. Likewise, the comparison between the observer and video data for the same trawls showed that in-trawl video observations alone are not sufficient to monitor bycatch, because captured animals may be entangled in parts of the net beyond the camera's field of view, or are too small or transparent to be seen on video.

Over three quarters of the bycatch landed on deck was discarded dead, which equates to an overall total mortality of at least 51% of incidentally caught wildlife. This calculation of total mortality is based on the conservative assumption that all individuals expelled from the net during a trawl were alive at the time of expulsion and survived, and that no animals discarded alive died from post-capture stress and injury. This assumption stems from the difficulty of verifying death through video analysis and leads to an under-estimate of total mortality, which is the sum of several factors compromising the survival of captured animals. Time in the net (especially in the case of air-breathing dolphins and reptiles), packing of the catch in the codend, stress of entanglement and restricted capacity to breathe due to immobilisation (for some shark species) can severely compromise the condition and survival of escapees (Stevens *et al.* 2000; Baum *et al.* 2003a; Broadhurst *et al.* 2006; Mandelman and Farrington 2007). Handling procedures on deck can also significantly affect the post-release survival of bycatch (Ross and Hokenson 1997; Davis 2002; Broadhurst *et al.* 2006). In the PTF, large animals were routinely shaken out of the net by rapid, winch-driven movements of the net before landing on deck; some large sharks and sawfish were immobilised by being wound onto the net drum to ensure the fishers' safety in removing them from the net; and small mallets were used to break the teeth off sawfish rostra so that they did not become further entangled (VFJ and SJA, Murdoch University, pers. obs.). Smaller or incapacitated animals that were released alive likely suffered high post-release mortality due to the abundance of predators and scavengers that follow the trawlers (Hill and Wassenberg 1990; Wassenberg and Hill 1990; Allen and Loneragan 2010). These factors are known to affect bycatch mortality in other trawl fisheries (Suuronen *et al.* 1995; Ross and Hokenson 1997; Mandelman and Farrington 2007) and indicate that total mortality is higher than that which we could calculate without reliable data on post-capture survival rates.

Under Australia's EPBC Act, fishers are required to report the bycatch of listed and protected species in Australian waters. For example, the numbers of dolphins caught in the PTF between the years 2008 and 2011, as reported in skippers logbooks, were 17, 19, 17 and 18, respectively (Fletcher and Santoro 2009; Fletcher and Santoro 2010; Fletcher and Santoro 2011; Fletcher and Santoro 2012). However, the rates of dolphin capture reported by independent observers varied between 1.6 and 3.7 times higher than those reported by skippers (Allen and Loneragan 2010), which would equate to annual catches of between 27 and 70 dolphins. Moreover, results from the in-trawl video analyses presented here indicate that the rate of fatal interactions of dolphins and other species is likely to be greater than that reported by skippers and observers, because of the expulsion of injured or dead animals through the bottom-opening escape hatches of the BRD.

The upward pushing response observed on video prevented at least two dolphins, a turtle and numerous sharks from locating the bottom-opening escape hatch, resulting in the presumed death of the dolphins and possible injury and stress to the turtle and sharks. This points to a need for improved BRDs, including sloped grids and the use of both top- and bottom-opening escape hatches. Top-opening escape hatches are relatively inexpensive and have successfully reduced the bycatch of common dolphins (*Delphinus delphis*) in England's pelagic bass pair trawl fishery (Kaiser and Spencer 1995) and that of turtles, large sharks and rays in Australia's Northern Prawn Fishery (Brewer *et al.* 2006). Given the conservation status of many of the species caught incidentally in the PTF, we recommend immediate and improved bycatch mitigation, as well as more comprehensive monitoring with in-trawl video and independent observer coverage. We further recommend carrying out data collection for future studies during commercial operations, as experimental trawls are normally shorter in duration, which has likely lead to over-estimates of survival rates in previous studies (Kaiser and Spencer 1995; Suuronen 2005).

Dolphins, many elasmobranchs, turtles, sea snakes, seahorses and pipefish all have life history characteristics that render them particularly vulnerable to targeted or incidental exploitation by fisheries (Heppell *et al.* 2000; Stevens *et al.* 2000; Ward 2001; Foster and Vincent 2004). Bycatch in commercial fisheries is considered the greatest immediate threat to cetaceans (Lewison *et al.* 2004; Reeves *et al.* 2005; Read 2008) and exacerbates the dramatic population declines of elasmobranch species taken in target fisheries for shark fin and other elasmobranch products (Baum *et al.* 2003b; Dulvy *et al.* 2008; Camhi *et al.* 2009). These concerns are augmented by the difficulty in determining levels of unaccounted bycatch, which represents a potentially significant source of additional fishing mortality (Alverson and Hughes 1996; Davis 2002). Our video analyses indicated that the total mortality rate may be up to one third higher than that reported by observers or skippers, highlighting the need for further research using methods that can quantify unaccounted mortality. Although not feasible in this study, monitoring larger species of concern in holding tanks instead of immediately releasing them after landing (e.g. as described in Mandelman and Farrington 2007), or tagging them (Campana *et al.* 2009), would facilitate obtaining more reliable estimates of post-capture mortality.

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Table 1. Scientific and common names and protection status (as per May 2013) under the International Union for the Conservation of Nature (IUCN) and the Australian Environmental Protection and Biodiversity Conservation (EPBC) Act 1999 of wildlife species that were recorded on video (V) and/or by an on-board observer (O) in 44 trawls in the Pilbara Fish Trawl Interim Managed Fishery in September 2008 - October 2009. The number of identified species in each major grouping is shown in parentheses.

Taxon	Common name	IUCN status	EPBC Act
Delphinidae (1)	**Dolphins**		
Tursiops truncatus	Common bottlenose dolphin (V, O)	Least Concern	Protected
Selachimorpha (10)	**Sharks**		
Carcharhinus amboinensis	Pigeye shark (V)	Data Deficient	Not listed
Carcharhinus plumbeus	Sandbar shark (V, O)	Vulnerable	Not listed
Carcharhinus tilstoni	Australian blacktip shark (O)	Least Concern	Not listed
Chiloscyllium punctatum	Brownbanded bamboo shark (O)	Near threatened	Not listed
Hemigaleus australiensis	Australian weasel shark (O)	Least concern	Not listed
Hemipristis elongata	Snaggletooth shark (O)	Vulnerable	Not listed
Loxodon macrorhinus	Sliteye shark (V, O)	Least Concern	Not listed
Rhizoprionodon acutus	Milk shark (V, O)	Least Concern	Not listed
Sphyrna lewini	Scalloped hammerhead (V)	Endangered	Not listed
Stegostoma fasciatum	Leopard shark (V)	Vulnerable	Not listed
Unidentified Carcharhinidae	Unidentified whaler sharks (V)	-	-
Batoidea (9)	**Rays**		
Himantura uarnak	Reticulate whipray (V, O)	Vulnerable	Not listed
Manta sp.	Manta ray (V)	Vulnerable	Not listed
Netrygon kuhlii	Bluespotted maskray (V, O)	-	Not listed
Pastinachus sephen	Cowtail stingray (V)	Data Deficient	Not listed
Taeniurops meyeni	Blotched fantail ray (V, O)	Vulnerable	Not listed
Unidentified Batoidea	Unidentified true rays (V, O)	-	-
Glaucostegus typus	Giant shovelnose ray (V)	Vulnerable	Not listed
Rhinobatus sainsburyi	Goldeneye shovelnose ray (V, O)	Least Concern	Not listed
Unidentified Rhinobatidae	Unidentified shovelnose rays (V)	-	-
Pristis zijsron	Green sawfish (V, O)	Critically Endangered	Protected
Rhynchobatus australiae	Whitespotted guitarfish (V, O)	Vulnerable	Not listed
Hydrophiidae (1)	**Sea snakes**		
Aipysurus laevis	Olive sea snake (V, O)	Least Concern	Protected
Unidientified Hydrophiidae	Unidentified sea snakes (V, O)	-	-
Cheloniidae (1)	**Turtles**		
Natator depressus	Flatback turtle (V, O)	Data Deficient	Protected
Sygnathidae (2)	**Pipefish**		
Solegnathus hardwickii	Pallid pipefish (V, O)	Data Deficient	Protected
Hippocampus sp.	Seahorse sp. (O)	Data Deficient	Protected

Table 2. Summaries of a) the numbers of non-target species caught, retained and expelled from trawl nets, based on video analysis of 44 trawls (22 with Grid 1; 22 with Grid 2) in the Pilbara Fish Trawl Interim Managed Fishery in September 2008-October 2009.

Taxon	Interactions	Retained	Expelled (%)
a) Grid 1 (n = 22)			
Dolphins	2	1	1 (50%)
Sharks	8	3	5 (63%)
Rays	19	9	10 (53%)
Sea snakes	3	3	0 (0%)
Turtles	0	0	0 (-)
Sygnathids	0	0	0 (-)
Total	**32**	**16**	**16 (50%)**
b) Grid 2 (n = 22)			
Dolphins	1	0	1 (100%)
Sharks	18	11	7 (39%)
Rays	12	10	2 (17%)
Sea snakes	19	16	3 (16%)
Turtles	1	1	0 (0%)
Sygnathids	3	3	0 (0%)
Total	**54**	**41**	**13 (24%)**
c) Both nets (n=44)			
Dolphins	3	1	2 (67%)
Sharks	26	14	12 (46%)
Rays	31	19	12 (39%)
Sea snakes	22	19	3 (14%)
Turtles	1	1	0 (0%)
Sygnathids	3	3	0 (0%)
Total	**86**	**57**	**29 (34%)**

Table 3. The total numbers and fate of wildlife landed on deck recorded by an independent observer for the same 44 trawls for video analysis from the Pilbara Fish Trawl Interim Managed Fishery in 2008-09.

Taxon	Landed	Discarded alive	Discarded dead
Dolphins	2	0	2
Sharks	66	6	60
Rays	53	18	35
Sea snakes	5	5	0
Turtles	1	1	0
Sygnathids	2	0	2
Total (>18 taxa)	**129**	**30 (23%)**	**99 (77%)**

Table 4. Ethogram describing behaviours exhibited by animals that interacted with a BRD in trawl nets of the Pilbara Fish Trawl Interim Managed Fishery between September 2008 and October 2009.

Behavioural event	Description
Entangled in mesh	Animal becomes caught in mesh by fins, head or tail
Tail caught in grid	Tail caught or stuck in exclusion grid
Push upward	Pushes against upper area of net, towards surface
Push downward	Pushes against bottom of net, towards sea floor
Push sideways	Pushes left or right against mid section of the net
Glides through grid to codend	Swims or squeezes through the semi-flexible bars of the exclusion grid in the direction of the codend
Successful escape top	Swims through mesh on upper surface of net (sea snakes only)
Successful escape bottom	Actively swims out of bottom opening escape hatch
Expelled through bottom hatch	Passively glides or falls through bottom opening escape hatch, often motionless
Remains in net alive	Remains in net after stressful interaction with grid or mesh; continues to move
Remains in net motionless	Remains in net motionless after stressful interaction with grid or mesh; assumed dead

Figure Title

Figure 1. Still images from video footage recorded inside operating trawl nets used in the Pilbara Fish Trawl Interim Managed Fishery, showing (*a*) Grid 1, (*b*) Grid 2 and (*c*) a shark interaction with Grid 2. The camera is behind each grid facing towards the mouth of the net.

Figure 1. Still images from video footage recorded inside operating trawl nets used in the Pilbara Fish Trawl Interim Managed Fishery, showing (*a*) Grid 1, (*b*) Grid 2 and (*c*) a shark interaction with Grid 2. The camera is behind each grid facing towards the mouth of the net.